High Frequency Acoustic Propagation Studies and Thermal Microstructure

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LONG-TERM GOAL

The long-range scientific objective of this program is to understand the environmental effects of oceanic microstructure on the propagation of high frequency sound in the ocean.

OBJECTIVES

The specific goal of this program was to develop a non-invasive in-situ technique for the observation of thermal microstructure which was based upon the thermal dependence of the Raman scatter of light. The hypothesis that we sought to explore was whether our multispectral low-light-level color camera (LUMIS) could be used to image the Raman emission spectra in a way which would allow the inference of thermal microstructure to a scale of 1 cm^3 and to a thermal resolution of .01 degrees C.

APPROACH

The Raman scatter of light has long been known to be subject to a thermally dependent component. The basic physics of the process dictates that oceanic water exists as equilibrium between a monomeric species and a polymeric species. These two distinct species of water give rise to inelastic scatter of light. The emission spectra consists of a doublet spectrum with some overlap of the wavebands as their widths are somewhat wider than the separation between them (about 10 nm). Numerous studies of the Raman spectral dependence of light have been accomplished and for some time, a lidar program was pursued to see if this effect could be used in order to provide a fast and non-invasive way for thermal profiling of the water column [1-10]. Our own investigations of this effect were motivated by our interest in the effects of small scale oceanic mircrostructure on the propagation of high frequency sound and the evolution of a low- light-level camera system (LUMIS) for the observation of color images. Towards this end, both lab experiments and also an at-sea experiment were preformed in order to explore the potential applicability of this method to the observation of thermal microstructure.

WORK COMPLETED

Lab experiments: Laboratory experiments were centered around the use of a new high powered Nd:YaG laser (Spectra Physics) which emitted light (3.2 W) at a wavelength of 532 nm. The camera and the laser emission were arranged so that the laser light illuminated a stripe of water which was 1 meter from the camera and also parallel to the image plane of the device. Two Raman emission wavelengths, corresponding to the peaks of the emission spectra, one at 640 nm and the other at 650 nm were imaged. The filters were chosen to have a bandwidth of 10 nm. In order to assess the ability of the system to monitor the water temperature, the temperature was changed very slowly from 18 C to 21 C and images of the Raman scatter using the two quadrants of the camera with the appropriate

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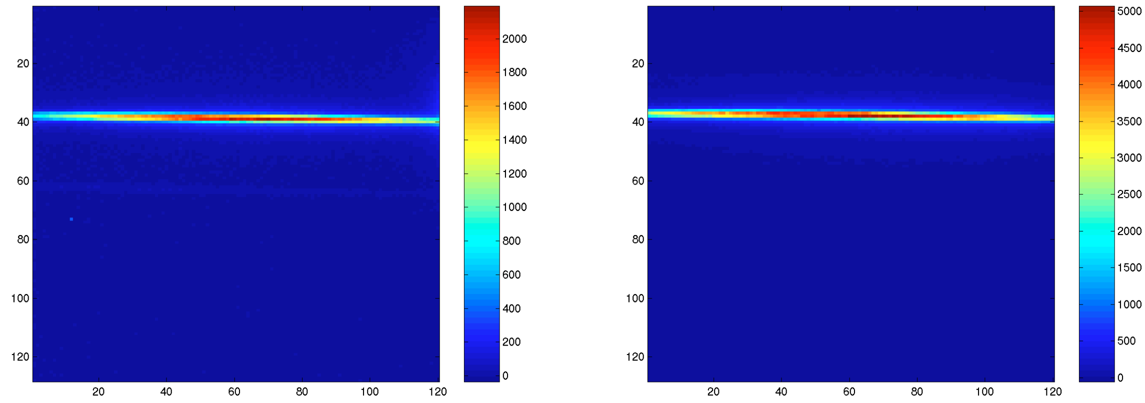
filters were taken. Consistent with previous results, the simple ratio of the total energy in these two wave bands, as monitored by the two channels of the camera provided an excellent and linear relationship between the inferred temperature and the observed temperature with a resolution of a approximately .05 degrees C over the temperature range indicated.

At-sea experiments: Based on the encouraging set of lab experiments (as above) the system was deployed from the RV Sproul during a three day cruise from Nov 23 - 25, 1997. The same laser and camera were used as in the lab experiments. Several vertical profiles were recorded which imaged the laser through the water at a range of approximately 1 meter from the camera. Emission spectra, as recorded by the camera where quite strong and spanned about half of the dynamic range of the camera system. In addition to the camera system and light source, a suite of oceanic sensors including temperature sensors were deployed so that an in-situ measurement of temperature could be compared with the inferred temperatures from this system. Camera exposures were taken over a 1 second period and the images were binned 5 by 5 in order to increase signal-to-noise while maintaining a high degree of image resolution (.5 cm x .5 cm).

RESULTS

The results from the at-sea experiments are shown in Figures 1,2. Figure 1 (a,b) shows the two Raman excitation images represented as bright horizontal lines in the images. Figure 1a corresponds to the 640 nm image and figure 1b corresponds to the 650 nm image. Note that the 650 image is about twice as bright as the 640 image, consistent with the lab results for temperatures in this range. It is also interesting to note that both of the images display some degree of small scale structure in the imaged patterns. This very likely corresponds to the existence of small scatterers and absorbers in the path of either the illuminating wavelength or the emission wavelength. Other images, taken over the course of these experiments, were used to record fluorescence emission at several wavelengths and demonstrated the presence of many small particles in the water column which resulted in a large degree of heterogeneity in the observed images (consistent with previous results). Unfortunately, in this case, the derived Raman temperature profiles were extremely noisy when compared with the temperature profiles as measured with our in-situ temperature sensors (Figure 2). The Raman profiles were obtained by integrating the total energy in the emitted light, as in the lab experiments, and simply taking the ratio of the two channels. In addition, since the results were so noisy, various other image processing strategies were used to attempt to get higher resolution from the Raman profiles, all of them yielded unsuccessful results to date, that is to say, we were unable to reproduce the observed temperature profile from processing of the Raman channels.

An interesting question arises in trying to understand the reason(s) that the performance of the temperature profiles were so poor. In contrast to previous investigators efforts, we sought to examine the effect over extremely short distances (1 m) where the selective attenuation of the spectrum would probably not be a problem. Previous limitations of the technique were credited to the extremely high signal-to-noise that is needed because the cumulative effect is about 1 % of



(a) (b)

Figure 1: Raman images of the light stripe at (a) 640 nm and (b) 650 nm.

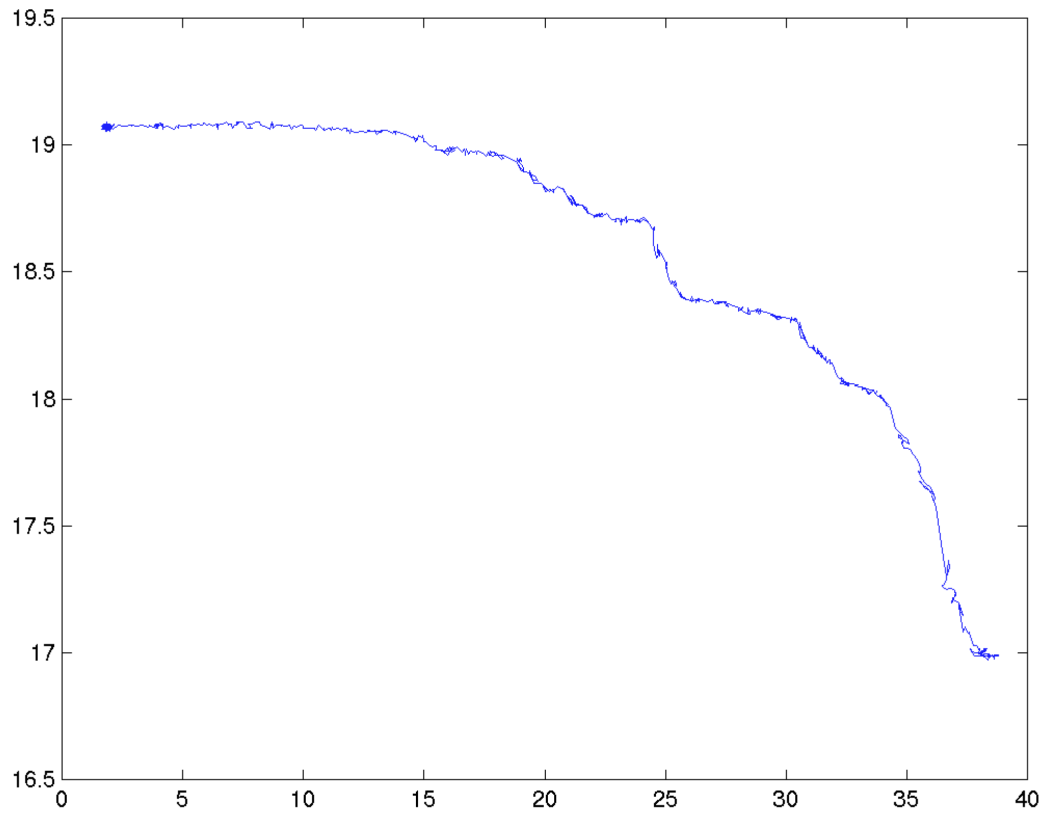


Figure 2: A profile of temperature (C) vs depth (m).

total number of photons per degree Centigrade of temperature resolution. Thus, in many cases the counting statistics (shot noise) tends to be the limitation. In the case under consideration here, a large number of photo-electrons were collected (10^6) so that, in principal the signal-to-noise should have been about 10^3 leading to an accuracy of about at least .1 degree Centigrade.

Other potential causes for the limitations in our ability to monitor the temperature using this method concern the scatter and/or absorption of the light on the way to the scatterers, after emission from the scatterers, the addition of any light due to other particles in the water and/or instrumentation effects related to the camera/laser, or the deployment. While we have not had time to examine each and every one of these possibilities in detail, some analysis has been done to try and track down the source of the problem.

In the case of systematic effects due to the camera/laser and or the deployment, a number of facts should be considered. First of all, the seas were extremely calm, leading to almost no ship heave (cms). This implies that the same volume of water was being imaged during the entire exposure time of the camera (decent rate was on the order of 3 m/min leading to integration over the exposure of the camera of 5 cm vertically). In addition, since the camera was working well it was certainly not the problem. On the other hand, the images are first processed by removing the dark current and bias which vary across the imaging chip. Since the 640 nm image and the 650 nm image are located in regions where the dark current is different, it is possible that the systematic differences that we were unable to see (the temperature profile) were due to cooling of the chip during deployment and our incorrect application of a bias and dark current correction. Since images taken of bias and dark current every 100 images were used to perform the calibration, we consider it unlikely, however it is possible.

In order to look for systematic effects which could prevent the method from working a useful distinction to make is between the incident and the emitted light. In the case of the incident light, it is unlikely that the variations in medium would be the problem. This is because taking the ratio of the two Raman bands normalizes out the effects of variability in the incident light. On the other hand, variations in the placement of small particles of the emitted light could affect the success of method. This is because after the light leaves the area of stimulation, since the camera lenses are spatially separated, the light traverses a different path to each of the lenses. It is certainly possible that the particles which are in between the lenses and the light stimulation area could lead to some additional noise that is in the system. In order to evaluate this hypothesis, the coherence in the examined microstructure was examined. It does appear that, to some extent the variations that we see in the light microstructure are due to different path lengths that the light traverses in propagating from the stimulated area to the camera. On the other hand, since these fluctuations are not very large, (typically .01 % of the total energy), it is unlikely that these contribute to the major effect.

Another interesting possibility is that the Raman emitted light is being influenced by the presence of fluorescent particles which are stimulated by the 532 light and that some of this light is leaking into the 640 and 650 band which we observe. If this is true, the presence of, say Chlorophyll emission whose maximum is at 680 could preferentially "leak" into the Raman channel at 650 and corrupt the temperature measurement. We consider this to be the most likely limitation on the method, as currently implemented. Unfortunately, since the camera system has only 4 channels, it was not possible to monitor both the chlorophyll fluorescence and the Raman emission. Presumably, a technique which permitted a more wide band image of the florescence emission of the water column could be used to explore this hypothesis and perhaps obtain better results than those demonstrated here.

IMPACT

Since our conclusion is that this technique will not work using the methods that we employed, we believe that the lessons that we have learned should be heeded by other researchers considering its use. Our conclusions are that small scale temperature microstructure cannot be measured by looking at Raman scatter at a small number of wavelengths.

TRANSITIONS

N/A

RELATED PROJECTS

Other projects in our group have concerned the use of the LUMIS camera system for the examination of small scale oceanic structure. This efforts have been funded by Biological Oceanography at ONR and also the National Science Foundation.

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